Carbon Dioxide Content in Golf Green Rhizosphere

S.-K. Chong,* Richard Boniak, S. Indorante, C.-H. Ok, and D. Buschschulte

ABSTRACT

Anaerobic soils limit the amount of free oxygen available in the rhizosphere, and therefore will impede grass root development and restrain nutrient availability for turf growth. An in situ study was conducted on existing greens to investigate the relationship between CO_2 content in the rhizosphere and turf quality. Nine greens were selected in the study. On each green, five 1-m-diam. circular plots were randomly selected for conducting the experiment. The greens were sampled seven times from August 1998 to August 1999. Data collected from each plot included turf quality index (TQI), CO_2 content, and physical properties of the rooting mixtures. Turf quality declined drastically when CO_2 content in the rhizosphere increased to 5 to 6 μL L^{-1} during the late summer season. The CO_2 content increased as water content in the root zone increased, but was inversely related to infiltration rate. Cultivation of a golf green may reduce CO_2 content in the rhizosphere, but the benefit of cultivation decreased with time.

Management of putting greens with high CO_2 content in the root zone has always been a dilemma to many golf course superintendents and turf researchers (Bunnell and McCarthy, 1999; Chong et al., 2000). The composition of the atmospheric air has been described in detail (Brady and Weil, 2000; Bremner and Blackmer, 1982; Bunnell and McCarthy, 1999; Chong et al., 2000). In the air, nitrogen is dominant at about 0.78 L L^{-1}. The remainder of the air is primarily O_2, Ar, and CO_2. These four gases make up >0.9999 L L^{-1} of the atmospheric air. However, the proportion of gases in soil air are different from that of the atmosphere. As a consequence of root respiration, microbial activity, and poor air exchange in the profile, CO_2 concentration in the soil air is higher than atmospheric levels.

Both CO_2 and O_2 play very important roles in plant biological process (Kohnke, 1968). The main biological processes are photosynthesis and respiration. Reports (Currie, 1970; Jury et al., 1991) indicate that the O_2 consumption rate can be as high as 60 to 75% of the CO_2 production rate, reaching a maximum of 24 g m^{-2} d^{-1}. It is important to note that CO_2 in the soil air is not only produced by plant root respiration, it also evolves from microbial breakdown of carbon-based organic compounds in the soil. The evolution rate of CO_2 may range from 1.2 to 35 g m^{-2} d^{-1} (Ghildyal and Tripathi, 1983) and depends very much upon plant, soil, and climatic conditions. However, it will be the highest when microbial and plant root activity is at a maximum, particularly in soils with poor drainage. Since soil air content in the root zone depends very much upon the aeration rate with the atmosphere, respiration rate of microorganism and plant roots, and solubility of gases in water, it is important to further understand the influences of soil air on turf growth. Most of the rhizospheric CO_2 and/or O_2 research has been conducted in agriculture fields. Only limited research on this topic has been conducted with recreation turf and sport fields.

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MATERIALS AND METHODS

This was an in situ study conducted on existing greens, therefore no control plot was set up for comparison in the experiment. The selected golf course is located in the Midwest, which belongs to the transition zone. The construction of this 18-hole golf course was completed in 1993. The greens were constructed in California style (Davis et al., 1990), employed without a layer of gravel. The root zone mix was placed over a native Sexton silt loam (fine, smectitic, mesic, Chromic Vertic Epiaqualfs) (Herman et al., 1979). The green mix was designed to be 30 cm deep. Located under the rooting mix are perforated plastic drainage tiles, 10 cm in diameter, lying in the native soil.

The greens were cultivated with a hollow tine aerifier (1.2-cm diam., 5- by 5-cm spacing, and 7.5 cm deep) during the first week of April and the last week of August in 1998. In 1999, the cultivation was performed again in the first week of April. In mid-June, the green was water-injection cultivated once with a hydrojet (Murphy and Rieke, 1994). No other cultivation was conducted until the end of experiment.

In the experiment, nine greens were randomly selected. On each green, five 1-m-diam. circular plots were again randomly selected for measurement. All the plots were marked by referencing to the sprinkler heads. Data collected from each plot included water content, CO_2 content, TQI, and soil physical and chemical properties. To be consistent and to minimize the climatic influence on CO_2 content, all experiments were conducted between 0600 and 1000 h with the condition that all greens had received regular irrigation and no rain fell for 3 d before the measurement. Water content was detected by time domain reflectometry (Soil Moisture Equipment, Santa Barbara, CA). Moisture content (from 0 to 20 cm) was measured at three different locations per plot and the mean value was used in the analysis. The in situ CO_2 content in the root zone was measured with a portable infrared gas analyzer (Sub-Air, Inc., Deep River, CT). In the measurement, a 16-cm (depth) hole was prepared with a 1.2-cm-diam. auger. Immediately after pulling the auger out from the green, a small plexiglass tube (8 cm long, 3.2 mm i.d., and 6.35 mm o.d.) was inserted into the hole for extracting CO_2. The inlet of the tube was inserted into the hole and kept at 8 cm below the green surface. The outflow of the tube was connected to a gas analyzer through a rubber stopper. The rubber stopper was used as a plug to prevent soil air contamination by the surrounding atmospheric air. Soil air was withdrawn directly from the hole by the infrared gas analyzer. Carbon dioxide content was detected as the soil air passed through the gas analyzer. In the measurement, the reading of CO_2 content started from zero

Abbreviations: TQI, turf quality index.

Table 1. The minimum, maximum, and mean air and soil temperature in the studied region 3 d before each measurement of CO_2 content. These data were obtained from the bulletins published by the National Climatic Data Center (Water and Atmospheric Resources Monitoring Program, 1998 and 1999).

Dates	Air temperature			Soil temperature		
	Min	Max	Mean	Min	Max	Mean
	°C					
26–28 Aug. 1998	15.1	30.3	23.7	22.3	26.3	24.3
26–28 Sept. 1998	16.9	33.5	24.5	20.6	23.3	22.1
20–22 Nov. 1998	−3.0	16.1	6.8	8.3	9.9	9.7
19–21 Mar. 1999	−1.1	12.1	5.7	5.9	8.1	7.1
7–9 June 1999	18.9	32.5	26.0	22.1	24.8	23.3
2–4 Aug. 1999	15.1	30.9	23.5	24.3	29.2	26.7
23–25 Aug. 1999	15.0	28.9	21.9	22.6	27.3	24.5

and gradually increased to a higher value, and finally decreased due to infiltration of surrounding atmospheric air into the rhizosphere. The highest value of the reading was recorded for analysis. The measurement was made once per plot and it took 2 to 3 min to complete. The CO_2 content collected from each measurement was plotted separately with the Weibull plotting position formula (Chow et al., 1988) for comparison.

Turf quality was scored at the same time when CO_2 was measured. Turf quality was judged by visualization of percentage cover, vigor, and color of the turf by the same person for the entire study. In the assessment, percentage cover in each plot was scored from 0 to 100%. The turf vigor and color were combined into one single value and rated from 1 to 9 (with 9 the best). The TQI was then calculated by (Boniak et al., 2001):

$$\text{TQI} = (\text{\% of cover} \times \text{vigor and color})/9$$

Totally, the experiment was conducted seven times for the entire study. The first measurement was conducted on 29 Aug. 1998, the day before cultivation was performed. One month (on 29 Sept. 1998) after the cultivation (with a 9-cm hollow tine), a second measurement was conducted. The last measurement made in 1998 was on 23 November. In 1999, four measurements were conducted. These were on 22 March, 10 June, and 5 and 26 August.

Infiltration was measured only once by a single-ring (12.7-cm diam.) infiltrometer on 26 Aug. 1999. The infiltrometer was inserted 15 cm into the soil. Before the measurement, to maintain a uniform antecedent condition, the soil profile was prewetted with 200 mL of water. Immediately after the water disappeared from the surface, another 200 mL of water was introduced into the infiltrometer. The infiltration time of the second water application was recorded for calculating infiltration rate.

RESULTS AND DISCUSSION

Temperature can be critical to CO_2 content in soil air. Unfortunately, no climatological data were collected from the experimental site during the experimental period. However, to have some knowledge about the variations in air and soil temperature of each measurement in the region, the minimum, maximum, and mean air and soil temperatures 3 d before the measurement were obtained from a weather station located at about 4 km south of the experimental site (Table 1). The data were published by the Illinois Climate Network (Water and Atmospheric Resources Monitoring Program, 1998 and 1999). Mean air and soil (at 10-cm depth) temperature of first (29 Aug. 1998) and second measurements (29 Sept. 1998) were very close to each other. But, temperature of the third measurement (23 Nov. 1998) was <10°C and close to the temperature of the late March measurement. The soil temperature of 5 Aug. 1999 was the warmest among all measurements.

Large variations in CO_2 content were found during the experimental period (Table 2). Carbon dioxide ranged from 0.12 in March to 13.1 μL L^{-1} in August. The golf green had high CO_2 content during the warm season, particularly in late August. High accumulation of CO_2 may be attributed to high soil microbial activity in the golf green rhizosphere. Cultivation reduced CO_2 in the rhizosphere (Fig. 1). Carbon dioxide content measured on 29 Aug. and 29 Sept. 1998 had an average reduction from 6.4 to 2.1 μL L^{-1}. But, the results of 23 November showed that CO_2 was higher than that of 29 Sept. 1998 with low soil temperature. The increasing CO_2 implied that benefit of cultivation decreased with time even under cooler temperature conditions. As expected, low CO_2 was detected in the early spring (Fig. 2), perhaps because of slow root growth and minimum microbial activities. In addition, the spring rain may also displace CO_2 out of the rooting zone. As temperatures became warmer, CO_2 content increased, especially in the late summer.

Statistical results showed a curvilinear relationship

Table 2. The range and mean value of turf quality index (TQI), water and CO_2 content in the root zone. The correlation coefficients (R) of CO_2 vs. water content and TQI of each measurement are listed in the last two columns.

Date	Soil water content			$C0_2$ content			TQI			r	
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	CO_2 vs. H_20	CO_2 vs. TQI
	cm^3 cm^{-3}			μL L^{-1}			%				
29 Aug. 1998	0.02	0.22	0.10 (59)†	0.91	9.68	6.41 (44)	36	100	78.5 (22)	0.71‡	−0.59***
29 Sept. 1998	0.09	0.29	0.20 (23)	0.18	5.43	2.14 (62)	29	99	72.8 (21)	0.87‡	−0.37*
23 Nov. 1998	0.16	0.37	0.24 (19)	0.30	6.73	2.98 (58)	65	94	82 (10)	0.69‡	−0.54***
22 Mar. 1999	0.15	0.39	0.25 (23)	0.12	4.75	1.34 (87)	54	87	74 (10)	0.36*	−0.38*
10 June 1999	0.11	0.28	0.19 (22)	0.34	8.84	4.06 (61)	90	100	98 (3)	0.83‡	−0.38**
5 Aug. 1999	0.10	0.27	0.18 (22)	0.28	8.80	3.96 (71)	67	100	92 (8)	0.89‡	−0.38**
26 Aug. 1999	0.11	0.27	0.19 (21)	0.33	13.10	5.32 (64)	69	100	92 (8)	0.79‡	−0.49**

* Significance of the regression at $P \leq 0.05$.
** Significance of the regression at $P \leq 0.01$.
*** Significance of the regression at $P \leq 0.001$.
† Values in parentheses are coefficient of variation in %.
‡ Significance of the regression at $P \leq 0.0001$.

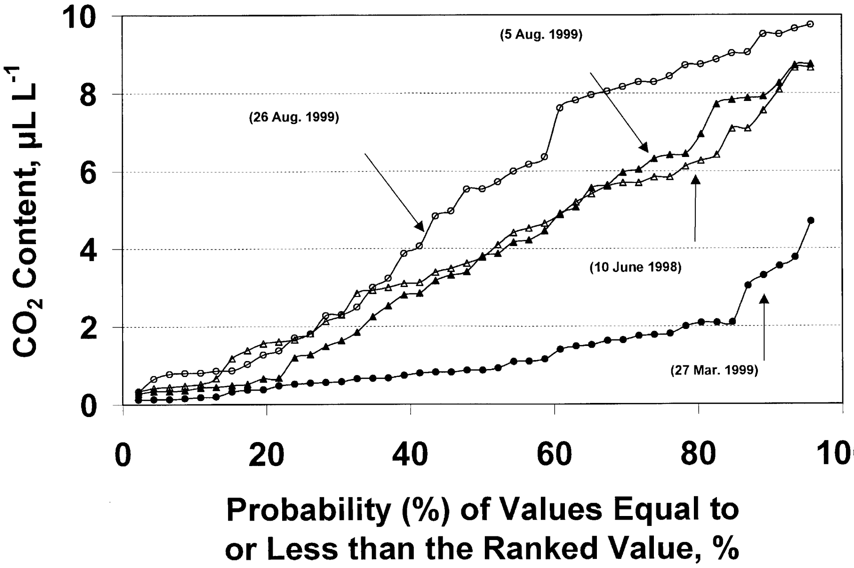

Fig. 1. Changes in CO_2 content in golf green rhizosphere before and after cultivation in the fall of 1998.

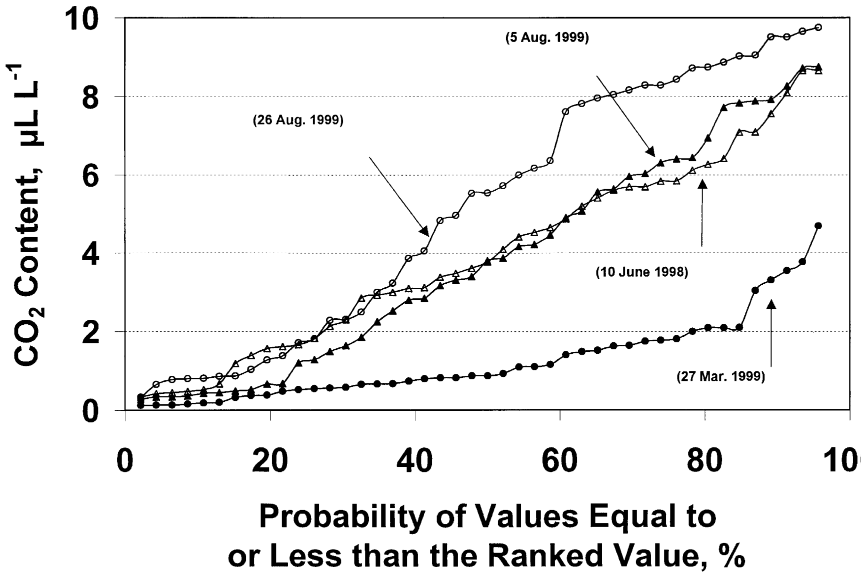

Fig. 2. Variations in CO_2 content in golf green rhizosphere, 1999.

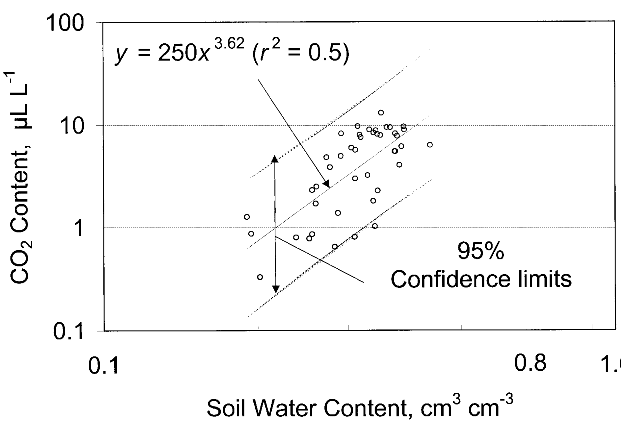

Fig. 3. Relationships between water and CO_2 contents in golf green rhizosphere. The data presented were measured on 26 Aug. 1999, right before the infiltration experiment was conducted.

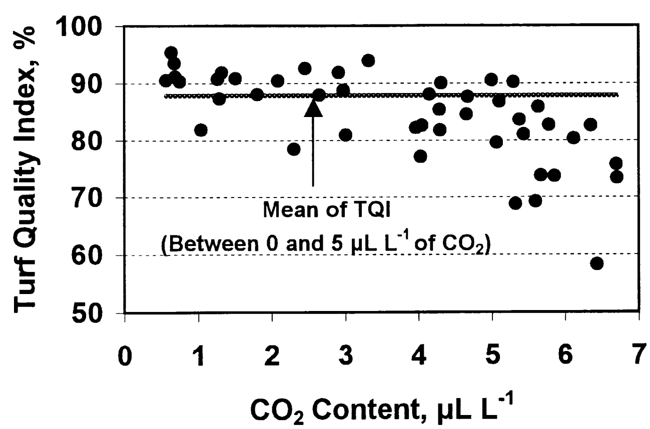

Fig. 4. Responses of turf quality at various CO_2 contents in golf green rhizosphere (mean of seven measurements). The solid line represented the mean value of TQI calculated between 0 to 5 $\mu L\ L^{-1}$.

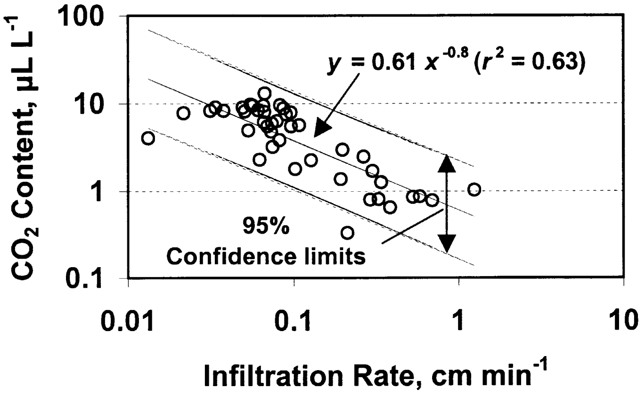

Fig. 5. Relationship between infiltration rate and CO_2 content measured on 26 Aug. 1999 in a golf green rhizosphere.

(see Fig. 3 for example) between soil moisture and CO_2 content. As water content in the rhizosphere increased, CO_2 also increased. The relationships were significantly related ($P \leq 0.0001$), except the measurement conducted on 22 Mar. 1998. Conversely, CO_2 was negatively related to turf quality. Even though the correlation coefficients between CO_2 and TQI were <0.6, they were statistically significant. Figure 4 shows the mean CO_2 and TQI values of the seven measurements of each plot. In Fig. 4, the solid line is the mean value of TQI calculated with the CO_2 content ranging from 0 to 5 µL L^{-1}. This reveals that when CO_2 content reached 5 µL L^{-1}, TQI decreased drastically. The phenomena was particularly significant during the summer season.

Statistical results also showed that infiltration rate and CO_2 were inversely related (Fig. 5) with a correlation coefficient of 0.79. It implies that a golf green with high infiltration rate will have a better aerated rhizosphere than those greens with poor drainage. In essence, soils with poor drainage will always result in poor turf quality.

CONCLUSIONS

Large variations in CO_2 content were found both spatially and temporarily in a golf green root zone. In general, CO_2 content in the golf green rhizosphere is low in the early spring. But, it increased to as high as 13 µL L^{-1} during the late growing season. Results indicated that when CO_2 content in the root zone accumulated higher than 5 µL L^{-1}, quality of the turf drastically declined. Cultivation of the green may reduce CO_2 content in the rhizosphere, but the benefit of cultivation decreased with time. Soil physical properties likely play a very important role in CO_2 content. Soils with high water content and poor drainage resulted in high CO_2 content. Inversely, soils with high infiltration rates may reduce the accumulation of CO_2 content in the profile. Therefore, to maintain a healthy turf, good drainage with a well-aerated rhizosphere is extremely important.

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